U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

TECHNICAL REPORT NO. 3-666

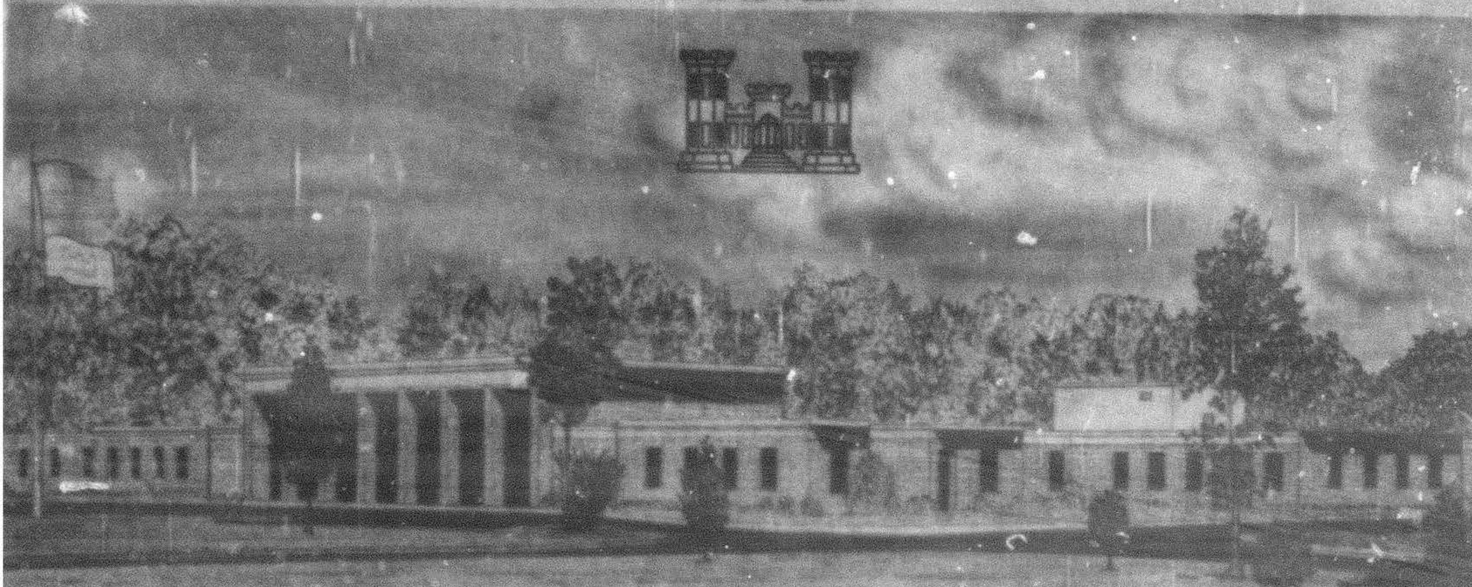
PERFORMANCE OF SOILS UNDER TIRE LOADS

Report 7

EXTENSION OF MOBILITY PREDICTION PROCEDURES TO RECTANGULAR-CROSS-SECTION TIRES IN COARSE-GRAINED SOIL

by

T. R. Patin



April 1972

Sponsored by Directorate of Research, Development and Engineering
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Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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13. ABSTRACT

The study reported herein was conducted to determine whether the sand mobility number that had been developed for circular-cross-section tires operating in a particular coarse-grained, air-dry soil could be used to predict the performance of rectangular-cross-section tires in the same or a second coarse-grained, air-dry soil. Five rectangular-section tires were tested in each of two coarse-grained soils, a desert sand from Yuma, Arizona, and a mortar-type sand from a river deposit near Vicksburg, Mississippi. The data collected in these tests were compared with relations previously developed from tests with circular-section tires in air-dry Yuma sand. Analysis of test results showed that the existing sand mobility number can be used to predict the performance of rectangular-section tires in both test sands.

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ARMY-MRC VICKSBURG, MISS

FOREWORD

The study reported herein was conducted in 1968 and 1969 in furtherance of Department of the Army Project 1T062103A046, "Trafficability and Mobility Research," Task 03, "Mobility Fundamentals and Model Studies," being conducted by personnel of the Mobility Research Branch (MRB), Mobility and Environmental (M&E) Division, U. S. Army Engineer Waterways Experiment Station (WES). This project is under the guidance and sponsorship of the Research, Development and Engineering Directorate, U. S. Army Materiel Command.

This study was conducted under the general supervision of Messrs. W. G. Shockley, Chief, M&E Division, and S. J. Knight, Assistant Chief, M&E Division, and Chief, MRB, and Dr. K.-J. Melzer of the MRB; and under the direct supervision of Mr. T. R. Patin of the MRB, who also prepared this report.

COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of WES during this study and preparation of this report. Messrs. J. B. Tiffany and F. R. Brown were Technical Directors.

CONTENTS

NOTATION

b	Tire section width, cm
d	Tire diameter, cm
D	Penetration depth, cm
D_r	Relative density, percent
G	Soil penetration resistance gradient, MN/m^3
h	Tire section height, cm
M, M_{20}	Torque and torque at 20 percent slip, respectively, m-N
P, P_{20}	Pull and pull at 20 percent slip, respectively, N
PR	Penetration resistance; numerical subscripts, e.g. PR_0, PR_1, etc., indicate equal depth intervals to depth of interest PR_D; kN/m^2
P_T	Towed force, N
r_a	Average active radius of tire, cm
W	Vertical load, N
z, z_{20}	Sinkage and sinkage at 20 percent slip, respectively, cm
δ	Tire deflection, cm

CONVERSION FACTORS, METRIC TO BRITISH UNITS OF MEASUREMENT

Metric units of measurement used in this report can be converted to British units as follows:

Multiply	By	To Obtain
centimeters	0.3937	inches
newtons	0.2248	pounds (force)
kilonewtons per square meter	0.1450	pounds per square inch
meganewtons per cubic meter	3.684	pounds per cubic inch
meter-newtons	0.7375	foot-pounds
grams per cubic centimeter	62.43	pounds per cubic foot

SUMMARY

The study reported herein was conducted to determine whether the sand mobility number that had been developed for circular-cross-section tires operating in a particular coarse-grained, air-dry soil could be used to predict the performance of rectangular-cross-section tires in the same or a second coarse-grained, air-dry soil.

Five rectangular-section tires were tested in each of two coarse-grained soils, a desert sand from Yuma, Arizona, and a mortar-type sand from a river deposit near Vicksburg, Mississippi. The data collected in these tests were compared with relations previously developed from tests with circular-section tires in air-dry Yuma sand.

Analysis of test results showed that the existing sand mobility number can be used to predict the performance of rectangular-section tires in both test sands.

PERFORMANCE OF SOILS UNDER TIRE LOADS

EXTENSION OF MOBILITY PREDICTION PROCEDURES TO RECTANGULAR-CROSS-SECTION TIRES IN COARSE-GRAINED SOIL

PART I: INTRODUCTION

Background

1. Tires with circular cross sections have been tested very extensively at the U. S. Army Engineer Waterways Experiment Station (WES) in one sand, an air-dry desert sand (Yuma sand); and empirical relations for predicting their performance have been developed on the basis of the results of these tests.[1,2,3] These relations did not necessarily apply to tires with rectangular cross sections, because the latter are geometrically and structurally different from the circular-section tires, nor to other sands. Therefore, rectangular-section tires needed to be tested on Yuma sand and at least one other sand to determine whether the existing sand mobility number could be used to predict performance of these tires, or whether new or revised numbers would have to be developed.

Purpose

2. The primary purpose of this study was to develop a performance prediction capability for rectangular-section tires in Yuma sand, either by using the existing sand mobility number established for circular-section tires in Yuma sand, by modifying it, or by developing an entirely new number, depending upon the test results. A secondary purpose was to investigate whether the applicable number for rectangular-section tires in Yuma sand also could be applied to performance of such tires in a different sand.

Scope

3. Forty programmed-slip and seven towed tests were conducted in

Yuma sand, and 16 programmed-slip tests were conducted in mortar sand; all were multiple-pass tests. Sand penetration resistance gradient G ranged from 0.86 MN/m^3* to 6.08 MN/m^3 for these tests. Five rectangular-section tires were used; each was tested at 15, 25, and 35 percent deflection. Loads ranged from 900 to 6000 N. The test data obtained from these tests were compared with curves established for circular-section tires, areas of agreement and disagreement were identified, and prediction curves for the rectangular-section tires were established when the circular-section tire curves were not applicable. All curves were visual lines of best fit.

Definitions

4. Most of the terms used in this study have been defined in earlier reports;[1,2,4] however, attention is called to one important change, i.e. the use of the more conventional symbol M instead of Q for torque. "Circular-section" or "rectangular-section" refers to the shape of the tire's cross section. The "average active radius r_a" of a tire is the undeflected radius minus one-half the maximum hard-surface deflection.

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* A table for converting metric to British units of measurements is given on page ix.

PART II: SOILS, TIRES, AND TEST PROCEDURES

Soils

5. Tests were conducted in two coarse-grained, cohesionless soils, one a sand from the desert near Yuma, Arizona (Yuma sand), and the other a sand from the Big Black River bottom near Vicksburg, Mississippi (mortar sand). Grain-size distribution curves are shown in fig. 1. The moisture content of these sands was kept below 0.5 percent during all the tests. A more complete description of these two sands can be found in references 5 and 6.

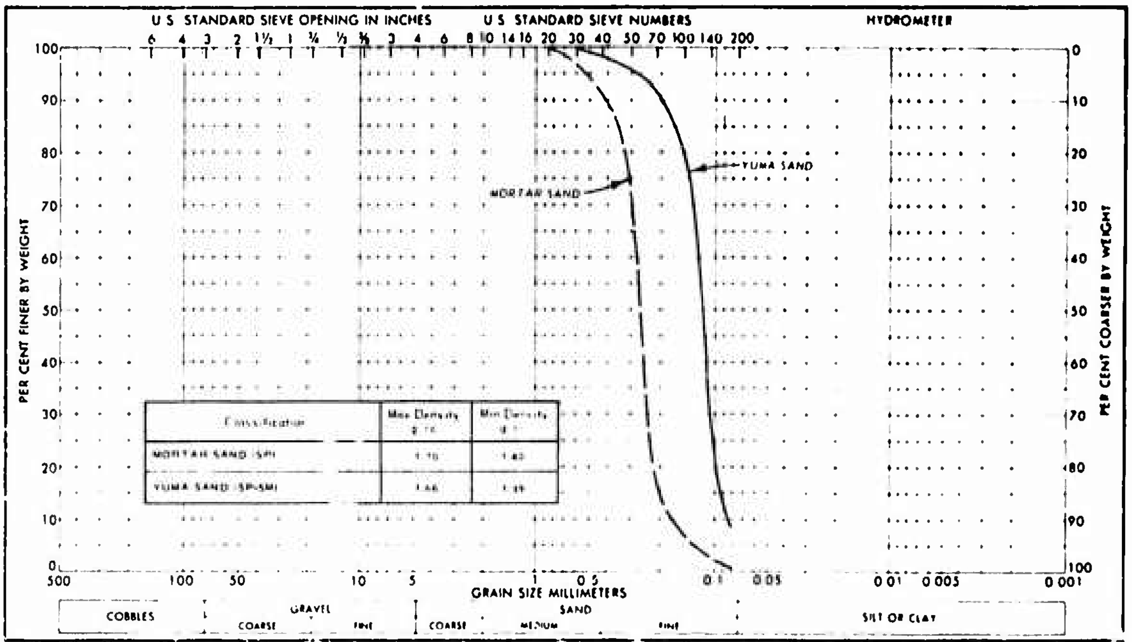

Fig. 1. Gradation and soil property data for the test sands

Tires

6. The following five rectangular-section tires were tested in this study (fig. 2): 16x6.50-8, 2-PR; 16x11.50-6, 2-PR; 16x15.00-6, 2-PR; 26x16.00-10, 4-PR; and 31x15.50-13, 4-PR. The circular-section tires considered were the 4.00-7, 2-PR, and the 9.00-14, 2-PR. Pertinent characteristics of all these tires are given in table 1.

Fig. 2. Rectangular-section tires tested

Test Procedures

7. The same basic procedures for multiple-pass programmed-slip and towed tests[2,4] were followed in all tests, except for one important improvement. The pull values recorded for all tests with both rectangular-section tires and circular-section tires were corrected for inertia effects[7] that existed when the test carriage was gradually decelerated during the programmed-slip tests.

PART III: PRESENTATION AND ANALYSIS OF DATA

Data Used

8. The original intent was to compare performance data developed in this study for rectangular-section tires with prediction curves for circular-section tires developed in a previous study.[2] This could not be done because of changes in test techniques and data acquisition, which led to improved data, i.e. the pull values were corrected for inertia effects (paragraph 7). The performance data used in this report for circular-section tires (table 2) are, therefore, from tests in which pull values were corrected: seven single-wheel one-pass tests with a 9.00-14 tire listed in reference 8, and a number of single-wheel multiple-pass tests with 9.00-14 and 4.00-7 tires listed in table 4 of reference 9. Tire and performance data for the rectangular-section tires are listed in table 3 herein.

9. In a number of tests, a negative pull was obtained at a positive 20 percent slip condition, and data from these tests were not used in the analysis, although they are listed in the data tables. Such a condition is possible only in the laboratory. Because of the physical setup (soil strength, wheel load, etc.) and the manner in which the tests are run in the laboratory, the wheel exerts a negative pull, i.e. the wheel is being pulled by the carriage, when the soil-wheel-load conditions are such that the force required to tow the wheel exceeds its forward thrust. If such a situation should occur with a vehicle, the result, of course, would be immobilization.

Tests in Yuma Sand

Sand mobility number

10. The sand mobility number N_s developed for circular-section tires in Yuma sand[2] is:

$$N_s = \frac{G(bd)^{3/2}}{W} \cdot \frac{\delta}{h}$$

where

G = cone penetration resistance gradient

b = maximum outside width of the cross section of the inflated, but unloaded, tire

d = outside diameter of the inflated, but unloaded, tire

W = the vertical load (force) applied to the tire through the axle

δ = tire deflection, i.e. the difference between the section height and the loaded section height

h = tire section height, i.e. the distance from the lip of the rim flange to the periphery of the treadless tire, measured along the vertical center line of the cross section of the inflated, but unloaded, tire

The G value in the equation above is the average slope of the penetration resistance versus depth curve and is calculated by the following equation:

$$G = \frac{2}{D}\left(\frac{PR_0 + PR_1 + PR_2 \ldots PR_D}{\text{number of PR readings}} - PR_0\right)$$

where

PR_0 = the penetration resistance reading when the base of the cone is flush with the soil surface, sometimes called surface or zero-depth reading

$PR_1, PR_2 \ldots PR_D$ = penetration resistance readings taken at equal depth intervals down to a depth D

D = depth to which G values are to be taken

11. The relations between mobility number N_s and the pull coefficient P/W (pull/load), torque coefficient M/Wr_a (torque/load × active radius), and sinkage coefficient z/d (sinkage/diameter), respectively, are shown in plate 1 for tests with the two circular-section tires (4.00-7 and 9.00-14). These performance curves form the basis for comparing the results of the tests with the rectangular-section tires with those with circular-section tires.

First-pass performance

12. Pull coefficient at 20 percent slip (P_{20}/W). The curve from plate 1a for P_{20}/W versus the sand mobility number for circular-section tires is compared in plate 2a (dashed line) directly with a

similar relation for the P_{20}/W data for rectangular-section tires shown in table 3. This comparison shows that the circular-section tire curve can be used to predict the pulls of the rectangular-section tires for N_s below 15; but for N_s above 15, a new curve (solid line) fits the rectangular-section tire data better.

13. Torque coefficient at 20 percent slip (M_{20}/Wr_a). The torque coefficient-sand mobility number data obtained from rectangular-section tire tests are plotted in plate 2b, together with the curve from plate 1b for circular-section tires. As is apparent, the same curve can be used to predict the performance of the rectangular-section tires and the circular-section tires.

14. Sinkage coefficient at 20 percent slip (z_{20}/d). The results presented in plate 2c show that the curve for sinkage of circular-section tires from plate 1c (dashed line) does not predict rectangular-section tire sinkage very well. For sand mobility numbers less than 10, this curve would predict sinkages smaller than actual, whereas for the higher values, larger than actual sinkage values would be predicted. However, here again, while the previously developed curve for circular-section tires does not serve to predict sinkage of rectangular tires, a new curve (solid line in plate 2c) defines a good relation of sinkage and sand mobility number.

15. Towed force coefficient (P_T/W). A curve for predicting towed force of circular-section tires in Yuma sand was not established because the data were limited, there being no towed force information available from reference 8 and results from only 10 tests with the 9.00-14 tire available from reference 9. Also, these 10 tests did not cover the full sand mobility number range.

16. The relation between the towed force coefficient P_T/W and the sand mobility number for rectangular-section tires, shown in plate 3, indicates that the sand mobility number can be used to predict the performance of rectangular-section tires in Yuma sand, and the line of best fit for these data can be used as a prediction curve.

Multiple-pass performance

17. Selection of [illegible] values to be used in analysis. There are

two choices in assigning values of penetration resistance gradient G for the characterization of sand strength in analysis of multiple-pass performance data: (a) use G values in the sand mobility number that have been measured before traffic, or (b) use G values measured before each pass. The first choice was used in this study because it is the only practical means of applying the sand mobility number to field conditions. To measure G before the passage of the second and third axles of a six-wheeled vehicle would be very difficult, if not impossible.

18. Pull coefficient at 20 percent slip (P_{20}/W). Prediction relations for second- and third-pass performance of circular-section tires are shown in plates 4a and 4c, respectively. These relations are plotted in plates 5a and 5c, together with the data obtained on the second and third passes with rectangular-section tires. The curves for the circular-section tires fit the data for the rectangular-section tires quite well, indicating that the circular-section tire curve can be used to predict pull performance of rectangular-section tires. The data scatter for the third pass is wider than that for the second pass, which, in turn, is wider than that for the first pass (plate 2a). The data from tests with the rectangular-section tires tend to show slightly more scatter than the data for the circular-section tires.

19. Torque coefficient at 20 percent slip (M_{20}/Wr_a). When the torque performance curves for second- and third-pass data for circular-section tires from plates 4b and 4d, respectively, are plotted in plates 5b and 5d, together with similar data for the rectangular-section tires, the circular-section tire curves again fit the rectangular-section tire data quite well, although the data scatter in plates 5b and 5d is fairly wide. This indicates the circular-section tire curves can be used to predict torque performance of the rectangular-section tires.

Tests in Mortar Sand

Method of analysis

20. Mortar sand was not included in the previous WES development

of the sand mobility number for circular-section tires; therefore, circular-section and rectangular-section tire performance in mortar sand could not be compared as has been done herein for Yuma sand. Thus, the analysis consisted of (a) determining whether the sand mobility number $\frac{G(bd)^{3/2}}{W} \cdot \frac{\delta}{h}$ could be used to collapse the data for rectangular-section tires in mortar sand, and if so, (b) developing prediction curves for this sand.

First-pass performance

21. Pull coefficient at 20 percent slip (P_{20}/W). The results of tests with rectangular-section tires in mortar sand show that the previously developed mobility number can be used to predict the performance of these tires (solid line, plate 6a). When this curve is compared with the curve (dashed line) for Yuma sand from plate 2a, the Yuma sand produces higher P_{20}/W values for a given sand mobility number than does the mortar sand. Although different curves are needed for the two sands, each can be used for prediction for the pertinent sand.

22. Torque coefficient at 20 percent slip (M_{20}/Wr_a). Apparently, the Yuma sand mobility number can also be used to predict the torque of rectangular-section tires in mortar sand with reasonably acceptable accuracy, as shown in plate 6b (solid line). For a given sand mobility number, less torque is required in mortar sand than in Yuma sand (dashed line). Here again, although different curves are needed for the two sands, each curve predicts reasonably well for the pertinent sand.

23. Sinkage coefficient at 20 percent slip (z_{20}/d). Sinkage of rectangular-section tires in mortar sand can be predicted by the sand mobility number (plate 6c); in fact, the same curve can be used for predicting sinkages in both Yuma and mortar sands.

24. Towed force coefficient at 20 percent slip (P_T/W). As in the other performance parameters, the towed force coefficient can also be predicted by the sand mobility number (plate 6d), and as in the sinkage coefficient at 20 percent slip, the same curve can be used to predict towed force coefficient in both Yuma and mortar sands.

25. Comparison of Yuma and mortar sand test results. Yuma sand

and mortar sand test results for the four first-pass performance parameters are compared in plate 6. To predict both pull and torque at 20 percent slip (plates 6a and 6b, respectively), separate curves are needed for the two sands. On the other hand, sinkage and towed force (plates 6c and 6d, respectively) can be predicted for the two sands by the same curve.

Relative Density Consideration

26. Because different curves are needed for predicting pull in Yuma and mortar sands (plate 6a), it is likely that G alone may not be an adequate common denominator representing the strength in all sand conditions. In an attempt to arrive at a common denominator (at least for the two sands considered in this study), the work done by Melzer[6] relating G to relative density D_r was examined (plate 7).

27. It is hypothesized that the two sands would behave similarly when they were at the same relative density. To test this hypothesis, the G values for the various mortar sand tests were converted into "equivalent" G values of Yuma sand at the same relative density. (Example: In mortar sand a value of $G = 2.0$ corresponds to a relative density of 62 percent (plate 7b); that same relative density of 62 percent in Yuma sand corresponds to $G = 1.4$ (plate 7a); thus, a G value of 2.0 in mortar sand has an equivalent value of 1.4 in Yuma sand. This value of $G = 1.4$ is then used in the sand mobility number for plotting mortar sand test results.)

Pull coefficient at 20 percent slip (P_{20}/W)

28. The data from plate 2a for the Yuma sand tests with rectangular-section tires are plotted in plate 8a, together with the Yuma sand equivalent values for the mortar sand, which were developed by using the procedures described in paragraph 27. When the converted values for the mortar sand are used, the curve for Yuma sand fits the mortar sand data quite well.

Torque coefficient at
20 percent slip (M_{20}/Wr_a)

29. As was done with the pull data the Yuma sand G equivalent was used to replot the mortar sand data in plate 8b, together with the Yuma sand data from plate 2b. The new plot shows that, after conversion, the torque at a given relative density required in mortar sand is still smaller than that required in Yuma sand (paragraph 22). A possible reason for this difference is discussed in paragraphs 30 and 31.

Sinkage coefficient at
20 percent slip (z_{20}/d)

30. When the mortar sand G values are converted to equivalent Yuma sand G values (paragraph 27 and plate 7) and replotted (plate 8c), together with the data for Yuma sand tests from plate 2c, the relations seem to separate rather than collapse. For a given relative density, less sinkage is encountered in mortar sand than in Yuma sand. A possible qualitative explanation for this can be found by considering the compressibility of the two sands. A method by which the modulus of compressibility can be calculated, if the maximum, minimum, and initial void ratios of the sand are known, is explained in reference 10: except for cases of extremely low relative densities and depending on the void ratio and pressure, the Yuma sand is more compressible than the mortar sand.

31. Although compressibility assumes an elastic medium and may not represent the entire case for wheels on soft soils, qualitatively it could explain the reason for the deeper sinkage in Yuma sand at a given relative density. This, in turn, would explain why less torque is required in mortar sand than in Yuma sand for a given pull.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

32\. Based on the study herein, the following conclusions were drawn.

a. First-pass pull coefficient at 20 percent slip in Yuma sand can be predicted reasonably well for sand mobility numbers below 15 by a common curve for circular-section and rectangular-section tires; but for mobility numbers above 15, separate curves are needed. On the other hand, multiple-pass pull coefficient for both rectangular- and circular-section tires can be predicted by the same curve. The sand mobility number previously developed with circular-section tires in the Yuma sand successfully collapsed the data for rectangular-section tires for the pull coefficient at 20 percent slip in mortar sand (plate 6a). Yuma sand produces a higher pull coefficient at 20 percent slip than does the mortar sand for a given sand mobility number; however, when a given G value for mortar sand at a certain relative density is converted to the G value for Yuma sand at the same relative density (paragraph 27), the test results for both sands fall along the same prediction curve (plate 8a).

b. Torque coefficient at 20 percent slip in Yuma sand for the first, second, and third passes (plates 2b, 4b, and 4d, respectively) can be represented by one performance curve for the two types of tires. The previously developed Yuma sand mobility number for circular-section tires apparently successfully collapses the data for the torque coefficient for rectangular-section tires in mortar sand (plate 6b). For both a given sand mobility number and a given relative density, less torque is required in mortar sand than in Yuma sand (plates 6b and 8b).

c. Separate curves are needed to predict first-pass sinkage coefficient at 20 percent slip in Yuma sand for circular-section tires and rectangular-section tires (plate 2d); but sinkage coefficient at 20 percent slip in mortar sand for rectangular-section tires can be predicted successfully by the Yuma sand mobility number developed with circular-section tires. Also, the curve used to predict sinkage of rectangular-section tires in Yuma sand can be used for mortar sand (plate 6c).

d. For a given relative density, more sinkage is encountered in Yuma sand than in mortar sand (plate 8c), which can be

explained qualitatively by the fact that Yuma sand is more compressible than mortar sand (paragraph 30).

e. First-pass towed force coefficient for rectangular-section tires in Yuma sand can be predicted by the Yuma sand mobility number (plate 3). Also, the towed force coefficient at 20 percent slip in mortar sand for rectangular-section tires can be predicted successfully by the Yuma sand mobility number developed with circular-section tires; in fact, the same curve can be used for rectangular-section tires in both Yuma and mortar sands (plates 6d).

f. For rectangular-section tires, Yuma sand and mortar sand require separate prediction curves for pull and torque coefficients at 20 percent slip (plates 6a and 6b, respectively), whereas Yuma sand and mortar sand have a common curve for sinkage coefficient at 20 percent slip and for towed force coefficient (plates 6c and 6d, respectively).

Recommendations

33. It is recommended that tests be conducted:

a. With circular-section tires in Yuma sand in which the pull measurements are corrected for inertia. These tests should be designed to cover an adequately wide range of sand mobility numbers so that these data can replace the earlier test results in which no correction was made.

b. With a selected number of circular-section tires in mortar sand to adequately determine the performance characteristics of these tires in mortar sand.

c. In several additional sands so that the relative density approach described herein can be further verified. The pertinent characteristics of these sands should be considerably different from those of the Yuma and mortar sands.

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Table 1

Characteristics of Test Tires

		Unloaded Dimensions, cm			Hard-Surface Dimensions, cm		
Tire	Load N	Section Width b	Section Height h	Diameter d	Deflection δ	Active Radius r_a	Deflection δ/h
			Circular-Section Tires				
9.00-14, 2-PR	600	20.7	15.8	71.2	4.0	33.6	0.25
	630	20.7	15.8	71.2	4.0	33.6	0.25
	680	20.7	15.8	71.2	4.0	33.6	0.25
	710	20.7	15.8	71.2	4.0	33.6	0.25
	720	20.7	15.8	71.2	4.0	33.6	0.25
	77[illegible]	20.8	15.9	71.4	4.0	33.7	0.25
	850	20.8	16.0	71.6	4.0	33.8	0.25
	860	20.8	16.0	71.6	4.0	33.8	0.25
	1050	20.9	16.0	71.6	4.0	33.8	0.25
	1060	20.9	16.0	71.6	4.0	33.8	0.25
	1070	20.9	16.0	71.6	4.0	33.8	0.25
	1240	20.9	16.0	71.6	4.0	33.8	0.25
	1290	20.9	16.0	71.6	4.0	33.8	0.25
	1490	20.9	16.0	71.6	4.0	33.8	0.25
	1530	20.9	16.0	71.6	4.0	33.8	0.25
	1560	20.9	16.0	71.6	4.0	33.8	0.25
	1600	20.9	16.0	71.6	4.0	33.8	0.25
	2020	21.0	16.0	71.6	4.0	33.8	0.25
	2470	21.0	16.0	71.6	4.0	33.8	0.25
	2680	21.0	16.2	72.0	4.0	34.0	0.25
	4290	21.0	16.2	72.0	4.0	34.0	0.25
	5120	21.1	16.3	72.2	4.1	34.0	0.25
	5310	21.1	16.3	72.2	4.1	34.0	0.25
4.00-7, 2-PR	200	10.5	7.8	35.7	2.0	16.8	0.25
	280	10.6	7.8	35.7	2.0	16.8	0.25
	550	10.6	7.8	35.7	2.0	16.8	0.25
	680	10.6	7.8	35.7	2.0	16.8	0.25
	1000	10.6	7.8	35.7	2.0	16.8	0.25
	1570	10.7	7.9	35.9	2.0	17.0	0.25
	2000	10.7	7.9	35.9	2.0	17.0	0.25
	2410	10.7	7.9	35.9	2.0	17.0	0.25
			Rectangular-Section Tires				
16x6.50-8, 2-PR	1000	16.3	8.7	40.9	1.3	19.8	0.15
	1560	16.4	8.9	41.3	1.3	20.0	0.15
	1000	16.3	8.4	40.3	2.1	19.1	0.25
	2980	16.4	8.9	41.3	2.2	19.6	0.25
	3960	16.5	9.1	41.7	2.3	19.7	0.25
	1000	16.3	8.1	39.7	2.8	18.4	0.35
	2020	16.3	8.6	40.7	3.0	18.8	0.35
16x11.50-6, 2-PR	1000	28.2	13.4	43.9	2.0	21.0	0.15
	2020	28.2	14.0	45.[illegible]	2.1	21.5	0.15
	3960	28.3	14.7	46.5	2.2	22.2	0.15
	1000	28.2	13.0	43.[illegible]	3.2	20.0	0.25
	2020	28.2	13.4	43.9	3.4	20.2	0.25
	1000	28.2	12.8	42.7	4.5	19.1	0.35
	3960	28.2	13.7	44.5	4.8	19.8	0.35
	5720	28.2	14.0	45.1	4.9	20.1	0.35
16x15.00-6, 2-PR	1000	38.6	13.2	44.2	2.0	21.1	0.15
	1210	38.6	13.2	44.2	2.0	21.1	0.15
	2020	38.6	13.5	44.8	2.0	21.4	0.15
	1000	33.6	12.6	43.0	3.2	19.9	0.25
	2020	38.6	13.2	44.2	3.3	20.4	0.25
	3960	38.6	13.6	45.0	3.4	20.8	0.25
	2020	38.6	13.0	43.8	4.6	19.6	0.35
26x16.00-10, 4-PR	2020	41.0	15.4	61.8	2.3	29.8	0.15
	3960	41.0	15.6	62.2	2.3	30.0	0.15
	2020	40.9	15.2	61.4	3.8	28.8	0.25
	5720	41.0	15.6	62.2	3.9	29.2	0.25
	3960	40.9	15.2	61.4	5.3	28.0	0.35
	4540	40.9	15.2	61.4	5.3	28.0	0.35
31x15.50-13, 4-PR	2020	38.1	19.4	75.4	2.9	36.2	0.15
	4450	38.2	19.7	76.0	3.0	36.5	0.15
	3960	38.1	19.4	75.4	4.8	35.3	0.25
	5340	33.1	19.7	76.0	4.9	35.6	0.25
	3960	38.1	19.3	75.2	6.8	34.2	0.35
	6000	38.1	19.6	75.8	6.9	34.4	0.35

Table 2

Results from Single-Wheel Tests Conducted at 20% Slip in Yuma Sand with Circular-Section Tires

Test No.	Pass No.	Penetration Resistance Gradient G 0-16 cm MN/m^3*	Deflection δ/h	Load W, N Design	Load W, N Test	Pull P N	Pull Coefficient P/W	Torque M, m-N	Torque Coefficient M/Wr_a	Sinkage z, cm	Sinkage Coefficient z/d	Sand Mobility Number N_s
					9.00-14, 2-Ph Tire							
1-68-50	1	5.37	0.25	1050	1070	490	0.458	209	0.578	0.0	0.000	72.6
	2		0.25	1050	1070	430	0.402	186	0.514	--	--	72.6
	3		0.25	1050	1050	400	0.377	179	0.500	--	--	73.3
-51	1	4.78	0.25	1560	1540	680	0.442	287	0.551	0.0	0.000	44.9
	2		0.25	1560	1530	550	0.359	255	0.493	--	--	45.2
	3		0.25	1560	1520	490	0.322	239	0.465	--	--	45.5
-52	1	3.69	0.25	1240	1200	530	0.442	225	0.555	0.0	0.000	44.5
	2		0.25	1240	1190	440	0.370	203	0.505	--	--	44.9
	3		0.25	1240	1180	400	0.339	194	0.486	--	--	45.3
-53	1	4.23	0.25	850	860	400	0.465	164	0.564	0.0	0.000	70.7
	2		0.25	850	890	360	0.404	155	0.515	--	--	68.3
	3		0.25	850	860	330	0.384	145	0.499	--	--	70.7
-54	1	2.99	0.25	600	600	270	0.450	118	0.585	0.8	0.011	70.5
	2		0.25	600	620	250	0.403	113	0.542	--	--	68.2
	3		0.25	600	610	240	0.393	104	0.507	--	--	69.3
-55	1	2.99	0.25	600	560	260	0.464	113	0.601	0.0	0.000	75.5
	2		0.25	600	560	230	0.411	100	0.531	--	--	75.5
	3		0.25	600	590	230	0.390	106	0.535	--	--	71.7
-56	1	3.04	0.25	770	780	360	0.462	152	0.579	0.0	0.000	55.8
	2		0.25	770	790	310	0.392	141	0.530	--	--	55.1
	3		0.25	770	780	290	0.372	136	0.517	--	--	55.8
-57	1	2.96	0.25	720	750	340	0.453	148	0.584	0.0	[illegible]	55.8
	2		0.25	720	740	300	0.405	133	0.532	--	--	56.6
	3		0.25	720	710	280	0.394	[illegible]	0.521	--	--	59.0
-58	1	2.66	0.25	860	890	400	0.449	172	0.572	1.3	0.018	42.9
	2		0.25	860	840	320	0.381	138	0.486	--	--	45.5
	3		0.25	860	810	290	0.358	138	0.504	--	--	47.2
-59	1	3.28	0.25	1070	1020	420	0.412	186	0.540	0.5	0.007	46.5
	2		0.25	1070	1090	400	0.367	179	0.486	--	--	43.5
	3		0.25	1070	1040	360	0.346	167	0.475	--	--	45.6
-60	1	3.45	0.25	1530	1520	620	0.408	[illegible]	0.518	0.3	0.004	32.8
	2		0.25	1530	1520	490	0.322	236	0.459	--	--	32.8
	3		0.25	1530	1510	440	0.291	221	0.433	--	--	33.1
-61	1	3.23	0.25	1490	1510	630	0.417	266	0.521	1.0	0.014	31.0
	2		0.25	1490	1520	500	0.329	235	0.457	--	--	30.8
	3		0.25	1490	1510	460	0.305	224	0.439	--	--	31.0
-62	1	2.99	0.25	2470	2420	810	0.335	388	0.474	1.4	0.020	18.0
	2		0.25	2470	2390	560	0.234	335	0.415	--	--	18.2
	3		0.25	2470	2390	520	0.218	320	0.396	--	--	18.2
-63	1	3.15	0.25	2680	2660	830	0.312	407	0.450	1.6	0.022	17.4
	2		0.25	2680	2660	590	0.222	363	0.401	--	--	17.4
	3		0.25	2680	2620	550	0.210	346	0.388	--	--	17.7
-64	1	3.61	0.25	680	670	300	0.448	125	0.555	0.2	0.003	76.2
	2		0.25	680	690	280	0.406	119	0.513	--	--	74.0
	3		0.25	680	620	120	0.194	106	0.509	--	--	82.4
-65	1	3.20	0.25	630	640	280	0.438	115	0.535	1.2	0.017	70.7
	2		0.25	630	600	250	0.417	108	0.536	--	--	75.4
	3		0.25	630	600	240	0.400	98	0.486	--	--	75.4
-66	1	3.45	0.25	1060	1070	470	0.439	201	0.556	0.3	0.004	46.7
	2		0.25	1060	1040	390	0.375	174	0.495	--	--	48.0
	3		0.25	1060	1040	390	0.375	168	0.478	--	--	48.0
-67	1	3.15	0.25	1050	1070	490	0.458	202	0.559	0.3	0.004	42.6
	2		0.25	1050	1050	390	0.371	175	0.493	--	--	43.4
	3		0.25	1050	1020	340	0.333	164	0.476	--	--	44.7
-68	1	3.58	0.25	2880	2910	930	0.320	457	0.462	1.9	0.026	18.1
	2		0.25	2880	2800	630	0.225	386	0.405	--	--	18.8
	3		0.25	2880	2780	590	0.212	380	0.402	--	--	18.9

(Continued)

* The values of G for each test series were measured before the first pass.

Table 2 (Concluded)

Test No.	Pass No.	Penetration Resistance Gradient G 0-16 cm MN/m^3	Deflection δ/h	Load W, N Design	Load W, N Test	Pull P N	Pull Coefficient P/W	Torque M, m-N	Torque Coefficient M/Wr_a	Sinkage z, cm	Sinkage Coefficient z/d	Sand Mobility Number N_s
						9.00-14, 2-PR Tire (Continued)						
1-65-69	1	2.80	0.25	3730	3560	880	0.247	548	0.453	2.7	0.038	11.6
	2		0.25	3730	3590	520	0.145	466	0.382	--	--	11.5
	3		0.25	3730	3510	540	0.154	442	0.370	--	--	11.7
-70	1	3.58	0.25	1600	1530	610	0.399	267	0.516	0.4	0.006	33.9
	2		0.25	1600	1510	480	0.318	232	0.455	--	--	34.3
	3		0.25	1600	1520	440	0.289	230	0.448	--	--	34.1
-71	1	2.63	0.25	1290	1270	510	0.402	225	0.524	1.0	0.014	30.0
	2		0.25	1290	1260	380	0.302	198	0.465	--	--	30.2
	3		0.25	1290	1240	350	0.282	190	0.453	--	--	30.7
-72	1	2.80	0.25	710	740	340	0.459	144	0.579	0.0	0.000	53.5
	2		0.25	710	730	310	0.425	127	0.518	--	--	54.3
	3		0.25	710	740	290	0.392	122	0.491	--	--	53.5
-73	1	2.99	0.25	2020	2000	750	0.375	342	0.506	1.1	0.015	21.8
	2		0.25	2020	1980	520	0.263	290	0.433	--	--	22.0
	3		0.25	2020	1930	480	0.249	273	0.418	--	--	22.6
-74	1	2.99	0.25	2020	1980	750	0.379	331	0.495	0.8	0.011	22.0
	2		0.25	2020	2000	560	0.280	287	0.425	--	--	21.[illegible]
	3		0.25	2020	1980	490	0.247	264	0.394	--	--	22.0
1-66-47	1	2.28	0.25	4290	4260	640	0.150	511	0.353	4.3	0.060	7.9
	2		0.25	4290	4220	450	0.107	517	0.360	--	--	7.9
	3		0.25	4290	4150	500	0.120	504	0.357	--	--	8.1
-48	1	2.20	0.25	5310	5140	480	0.093	689	0.393	6.5	0.090	6.4
	2		0.25	5310	5050	360	0.071	633	0.367	--	--	6.5
	3		0.25	5310	5080	440	0.087	626	0.361	--	--	6.4
-49	1	1.44	0.25	5120	4880	180	0.037	681	0.409	9.4	0.130	4.4
	2		0.25	5120	4880	330	0.068	652	0.392	--	--	4.4
	3		0.25	5120	4840	400	0.083	613	0.371	--	--	4.4
D-69-0003-1	1	[illegible].0	0.25	8180	--	--	-0.02	--	0.40	--	0.085	5.5
-0004-1	1	2.6	0.35	8180	--	--	0.06	--	0.36	--	0.101	6.7
-0005-1	1	2.3	0.35	8180	--	--	0.05	--	0.38	--	0.110	5.9
-0007-1	1	2.2	0.15	4000	--	--	0.09	--	0.38	--	0.086	5.8
-0050-1	1	2.2	0.25	4000	--	--	0.20	--	0.39	--	0.035	12.1
-0051-1	1	3.1	0.25	8180	--	--	0.03	--	0.38	--	0.069	5.8
-0052-1	1	3.1	0.35	8180	--	--	0.18	--	0.35	--	0.052	9.4
-0058-1	1	5.9	0.35	8180	--	--	0.27	--	0.40	--	0.030	16.1
						4.00-7, 2-PR Tire						
1-66-30	1	4.59	0.25	1000	1040	200	0.192	69	0.394	1.9	0.053	8.1
	2		0.25	1000	1030	70	0.068	54	0.311	--	--	8.2
	3		0.25	1000	1010	60	0.059	53	0.311	--	--	8.4
-31	1	4.53	0.25	680	690	180	0.261	49	0.421	1.0	0.028	12.1
	2		0.25	680	690	100	0.145	42	0.361	--	--	12.1
	3		0.25	680	670	90	0.134	41	0.363	--	--	12.4
-32	1	4.91	0.25	550	520	160	0.308	41	0.468	1.4	0.039	17.4
	2		0.25	550	600	110	0.183	38	0.376	--	--	15.1
	3		0.25	550	600	110	0.183	38	0.376	--	--	15.1
-33	1	4.64	0.25	280	290	100	0.345	24	0.491	0.6	0.017	29.4
	2		0.25	280	290	80	0.276	23	0.471	--	--	29.4
	3		0.25	280	280	70	0.250	20	0.424	--	--	30.5
-34	1	4.72	0.25	200	190	80	0.421	18	0.562	0.5	0.014	45.1
	2		0.25	200	200	60	0.300	16	0.475	--	--	42.8
	3		0.25	200	200	60	0.300	16	0.475	--	--	42.8
-35	1	4.29	0.25	1570	1550	180	0.116	91	0.346	2.3	0.064	5.2
	2		0.25	1570	1520	20	0.013	91	0.353	--	--	5.3
	3		0.25	1570	1520	-10	-0.007	95	0.369	--	--	5.3
-36	1	4.59	0.25	2000	2000	170	0.085	123	0.363	3.0	0.084	4.3
	2		0.25	2000	1950	-30	-0.015	119	0.360	--	--	4.4
	3		0.25	2000	1930	-80	-0.041	119	0.364	--	--	4.5
-37	1	4.40	0.25	2410	2380	-30	-0.013	133	0.332	4.0	0.111	3.5
	2		0.25	2410	2310	-140	-0.061	137	0.352	--	--	3.6
	3		0.25	2410	2290	-190	-0.083	137	0.355	--	--	3.6

Table 3

Results from Single-Wheel, Programmed-Slip Tests in Yuma and Mortar Sands with Rectangular-Section Tires

Tire	Test No.	Pass No.	Test Condition	Penetration Resistance Gradient G 0-16 cm MN/m³*	Deflection δ/h	Load W, N Design	Load W, N Test	Pull P N	Pull Coefficient P/W	Torque M m-N	Torque Coefficient M/Wr_a	Sinkage z, cm	Sinkage Coefficient z/d	Towed Force P_T, N	Towed Force Coefficient P_T/W	Sand Mobility Number N_s	Sand Mobility Number N_{se}**
								Yuma Sand									
16x6.50-8, 2-PR	A68-0061-1	1	20% slip	1.17	0.15	1000	910	-50	-0.055	64	0.355	6.0	0.147	--	--	3.3	--
		2	20% slip	1.17	0.15	1000	950	0	0.000	60	0.319	--	--	--	--	3.2	--
		3	20% slip	1.17	0.15	1000	940	20	0.021	54	0.290	--	--	--	--	3.2	--
	A68-0066-1	1	20% slip	3.71	0.15	1000	1010	210	0.208	77	0.385	1.8	0.044	--	--	9.5	--
		1	Towed	3.71	0.15	1000	1040	--	--	--	--	--	--	120	0.115	9.2	--
		2	20% slip	3.71	0.15	1000	1000	100	0.100	69	0.348	--	--	--	--	9.6	--
		3	20% slip	3.71	0.15	1000	970	80	0.082	60	0.312	--	--	--	--	9.9	--
	A68-0063-1	1	20% slip	2.69	0.15	1560	1490	100	0.067	108	0.362	5.2	0.126	--	--	4.8	--
		2	20% slip	2.69	0.15	1560	1500	0	0.000	99	0.330	--	--	--	--	4.7	--
		3	20% slip	2.69	0.15	1560	1510	0	0.000	98	0.325	--	--	--	--	4.7	--
	A68-0067-1	1	20% slip	4.37	0.25	1000	990	420	0.424	94	0.497	0.3	0.007	--	--	18.6	--
		1	Towed	4.37	0.25	1000	1000	--	--	--	--	--	--	30	0.030	18.4	--
		2	20% slip	4.37	0.25	1000	1000	230	0.230	71	0.372	--	--	--	--	18.4	--
		3	20% slip	4.37	0.25	1000	990	200	0.202	62	0.328	--	--	--	--	18.6	--
	A68-0064-1	1	20% slip	2.77	0.25	2980	2910	-120	-0.041	217	0.381	6.2	0.150	--	--	4.2	--
		2	20% slip	2.77	0.25	2980	2880	-220	-0.076	206	0.366	--	--	--	--	4.2	--
		3	20% slip	2.77	0.25	2980	2870	-210	-0.073	193	0.344	--	--	--	--	4.3	--
	A68-0065-1	1	20% slip	2.55	0.25	3960	3890	-650	-0.167	339	0.442	10.6	0.254	--	--	3.0	--
		2	20% slip	2.55	0.25	3960	3860	-530	-0.137	297	0.391	--	--	--		3.0	--
	A68-0062-1	1	20% slip	1.68	0.35	1000	1010	270	0.267	76	0.408	2.5	0.063	--	--	9.6	--
		1	Towed	1.68	0.35	1000	1020	--	--	--	--	--	--	130	0.127	9.5	--
		2	20% slip	1.68	0.35	1000	990	200	0.202	71	0.389	--	--	--	--	9.8	--
		3	20% slip	1.68	0.35	1000	970	190	0.196	60	0.335	--	--	--	--	10.0	--
	A68-0060-1	1	20% slip	0.95	0.35	2020	1900	-320	-0.168	148	0.413	10.5	0.258	--	--	3.0	--
		2	20% slip	0.95	0.35	2020	1890	-70	-0.037	114	0.320	--	--	--	--	3.0	--
		3	20% slip	0.95	0.35	2020	1900	30	0.016	125	0.349	--	--	--	--	3.0	--
	A68-0068-1	1	20% slip	5.49	0.35	2020	2010	810	0.403	182	0.480	0.8	0.020	--	--	16.3	--
		1	Towed	5.49	0.35	2020	2010	--	--	--	--	--	--	80	0.040	16.3	--
		2	20% slip	5.49	0.35	2020	2000	400	0.200	141	0.374	--	--	--	--	16.4	--
		3	20% slip	5.49	0.35	2020	2000	320	0.160	122	0.324	--	--	--	--	16.4	--
	A68-0069-1†	1	Towed	1.15	0.15	1000	950	--	--	--	--	--	--	510	0.537	3.1	--
	A68-0072-1†	1	Towed	2.71	0.15	1560	1540	--	--	--	--	--	--	370	0.240	4.7	--
	A68-0073-1†	1	Towed	2.90	0.25	2980	2960	--	--	--	--	--	--	1370	0.463	4.3	--
	A68-0071-1†	1	Towed	1.24	0.35	2020	1910	--	--	--	--	--	--	1370	0.717	3.9	--
16x11.50-6, 2-PR	A68-0077-1	1	20% slip	1.68	0.15	1000	930	210	0.226	84	0.431	2.1	0.048	--	--	11.8	--
		1	Towed	1.68	0.15	1000	960	--	--	--	--	--	--	120	0.125	11.4	--
		2	20% slip	1.68	0.15	1000	970	130	0.134	76	0.374	--	--	--	--	11.3	--
		3	20% slip	1.68	0.15	1000	1000	120	0.120	70	0.334	--	--	--	--	11.0	--
	A68-0075-1	1	20% slip	1.21	0.15	2020	1940	-130	-0.067	159	0.381	7.0	0.155	--	--	4.2	--
		2	20% slip	1.21	0.15	2020	1920	-20	-0.010	136	0.329	--	--	--	--	4.3	--
		3	20% slip	1.21	0.15	2020	1920	-10	-0.005	126	0.305	--	--	--	--	4.3	--
	A68-0080-1	1	20% slip	1.75	0.15	3960	3830	-460	-0.120	342	0.403	8.8	0.189	--	--	3.3	--
		2	20% slip	1.75	0.15	3960	3800	-360	-0.095	304	0.361	--	--	--	--	3.3	--
		3	20% slip	1.75	0.15	3960	3850	-380	-0.099	286	0.335	--	--	--	--	3.3	--

(Continued)

* The values of G for each test series were measured before the first pass.
** Applicable only to mortar sand; see sheet 4 of this table. Sand mobility number computed by using the Yuma sand equivalent of the mortar sand G value (paragraph 27 of text).
† Not a programmed-slip test; the tire was simply towed over the soil.

Table 3 (Continued)

Tire	Test No.	Pass No.	Test Condition	Penetration Resistance Gradient G 0-16 cm MN/m^3	Deflection δ/h	Load W, N Design	Load W, N Test	Pull P N	Pull Coefficient P/W	Torque M m-N	Torque Coefficient M/Wr$_a$	Sinkage z, cm	Sinkage Coefficient z/d	Towed Force P_T, N	Towed Force Coefficient P_T/W	Sand Mobility Number N_s	Sand Mobility Number N_{se}
							Yuma Sand (Continued)										
16x11.50-6, 2-PR (Continued)	A68-0081-1	1	20% slip	2.74	0.25	1000	1010	480	0.475	114	0.566	0.4	0.009	--	--	28.7	--
		1	Towed	2.74	0.25	1000	1000	--	--	--	--	--	--	50	0.050	29.0	--
		2	20% slip	2.74	0.25	1000	1010	340	0.337	94	0.467	--	--	--	--	28.7	--
		3	20% slip	2.74	0.25	1000	990	270	0.273	86	0.436	--	--	--	--	29.3	--
	A68-0076-1	1	20% slip	1.10	0.25	2020	1930	60	0.031	156	0.399	6.4	0.146	--	--	6.2	--
		2	20% slip	1.10	0.25	2020	1940	110	0.057	136	0.346	--	--	--	--	6.2	--
		3	20% slip	1.10	0.25	2020	1970	160	0.081	130	0.326	--	--	--	--	6.1	--
	A68-0078-1	1	20% slip	1.82	0.25	2020	2020	440	0.218	179	0.438	3.0	0.068	--	--	9.8	--
		1	Towed	1.82	0.25	2020	2030	--	--	--	--	--	--	300	0.148	9.8	--
		2	20% slip	1.82	0.25	2020	2010	240	0.119	160	0.393	--	--	--	--	9.9	--
		3	20% slip	1.82	0.25	2020	2000	250	0.125	146	0.360	--	--	--	--	9.9	--
	A68-0083-1	1	20% slip	3.55	0.35	1000	1040	500	0.481	120	0.604	0.0	0.000	--	--	49.9	--
		1	Towed	3.55	0.35	1000	1040	--	--	--	--	--	--	70	0.067	49.9	--
		2	20% slip	3.55	0.35	1000	1030	450	0.437	110	0.559	--	--	--	--	50.4	--
		3	20% slip	3.55	0.35	1000	1020	400	0.392	105	0.539	--	--	--	--	50.9	--
	A68-0082-1	1	20% slip	3.78	0.35	3960	3890	1330	0.342	404	0.523	1.1	0.025	--	--	15.1	--
		1	Towed	3.78	0.35	3960	3920	--	--	--	--	--	--	330	0.084	15.0	--
		2	20% slip	3.78	0.35	3960	3830	570	0.149	312	0.410	--	--	--	--	15.4	--
		3	20% slip	3.78	0.35	3960	3870	390	0.101	289	0.376	--	--	--	--	15.2	--
	A68-0079-1	1	20% slip	1.04	0.35	5720	5570	-720	-0.129	479	0.428	11.4	0.253	--	--	3.0	--
		2	20% slip	1.04	0.35	5720	5560	-320	-0.058	428	0.383	--	--	--	--	3.0	--
		3	20% slip	1.04	0.35	5720	5530	-190	-0.034	386	0.347	--	--	--	--	3.0	--
16x11.50-6, 2-PR	A68-0084-1†	1	Towed	1.30	0.15	2020	2020	--	--	--	--	--	--	850	0.421	4.4	--
	A68-0087-1†	1	Towed	1.86	0.15	3960	3840	--	--	--	--	--	--	2190	0.570	3.5	--
	A68-0085-1†	1	Towed	1.30	0.25	2020	2040	--	--	--	--	--	--	470	0.230	6.9	--
16x15.00-6, 2-PR	A68-0097-1	1	20% slip	4.32	0.15	1000	1010	440	0.436	111	0.521	0.6	0.014	--	--	45.2	--
		1	Towed	4.32	0.15	1000	1020	--	--	--	--	--	--	20	0.020	44.8	--
		2	20% slip	4.32	0.15	1000	1040	220	0.212	80	0.365	--	--	--	--	43.9	--
		3	20% slip	4.32	0.15	1000	1020	170	0.167	74	0.344	--	--	--	--	44.8	--
	A68-0092-1	1	20% slip	1.86	0.15	1210	1210	320	0.264	102	0.400	1.5	0.034	--	--	16.2	--
		1	Towed	1.86	0.15	1210	1240	--	--	--	--	--	--	130	0.105	15.9	--
		2	20% slip	1.86	0.15	1210	1180	150	0.127	84	0.337	--	--	--	--	16.7	--
		3	20% slip	1.86	0.15	1210	1220	140	0.115	82	0.319	--	--	--	--	16.1	--
	A68-0093-1	1	20% slip	1.79	0.15	2020	2000	220	0.110	172	0.402	3.3	0.074	--	--	9.7	--
		2	20% slip	1.79	0.15	2020	2000	40	0.020	145	0.339	--	--	--	--	9.7	--
		3	20% slip	1.79	0.15	2020	2000	30	0.015	132	0.308	--	--	--	--	9.7	--
	A68-0088-1	1	20% slip	0.95	0.15	2020	2010	-120	-0.060	160	0.372	4.2	0.094	--	--	5.1	--
		2	20% slip	0.95	0.15	2020	2000	-30	-0.015	140	0.327	--	--	--	--	5.1	--
		3	20% slip	0.95	0.15	2020	2000	-20	-0.010	126	0.294	--	--	--	--	5.1	--
	A68-0096-1	1	20% slip	3.16	0.25	1000	1020	530	0.520	122	0.601	0.4	0.009	--	--	52.4	--
		1	Towed	3.16	0.25	1000	1020	--	--	--	--	--	--	30	0.029	52.4	--
		2	20% slip	3.16	0.25	1000	1020	420	0.412	104	0.512	--	--	--	--	52.4	--
		3	20% slip	3.16	0.25	1000	1000	340	0.340	88	0.442	--	--	--	--	53.4	--
	A68-0095-1	1	20% slip	2.36	0.25	2020	1980	720	0.364	194	0.479	0.8	0.018	--	--	21.0	--
		1	Towed	2.36	0.25	2020	1990	--	--	--	--	--	--	140	0.070	20.9	--
		2	20% slip	2.36	0.25	2020	2040	440	0.216	160	0.384	--	--	--	--	20.4	--
		3	20% slip	2.36	0.25	2020	1960	310	0.158	141	0.352	--	--	--	--	21.2	--

(Continued)

† Not a programmed-slip test; the tire was simply towed over the soil.

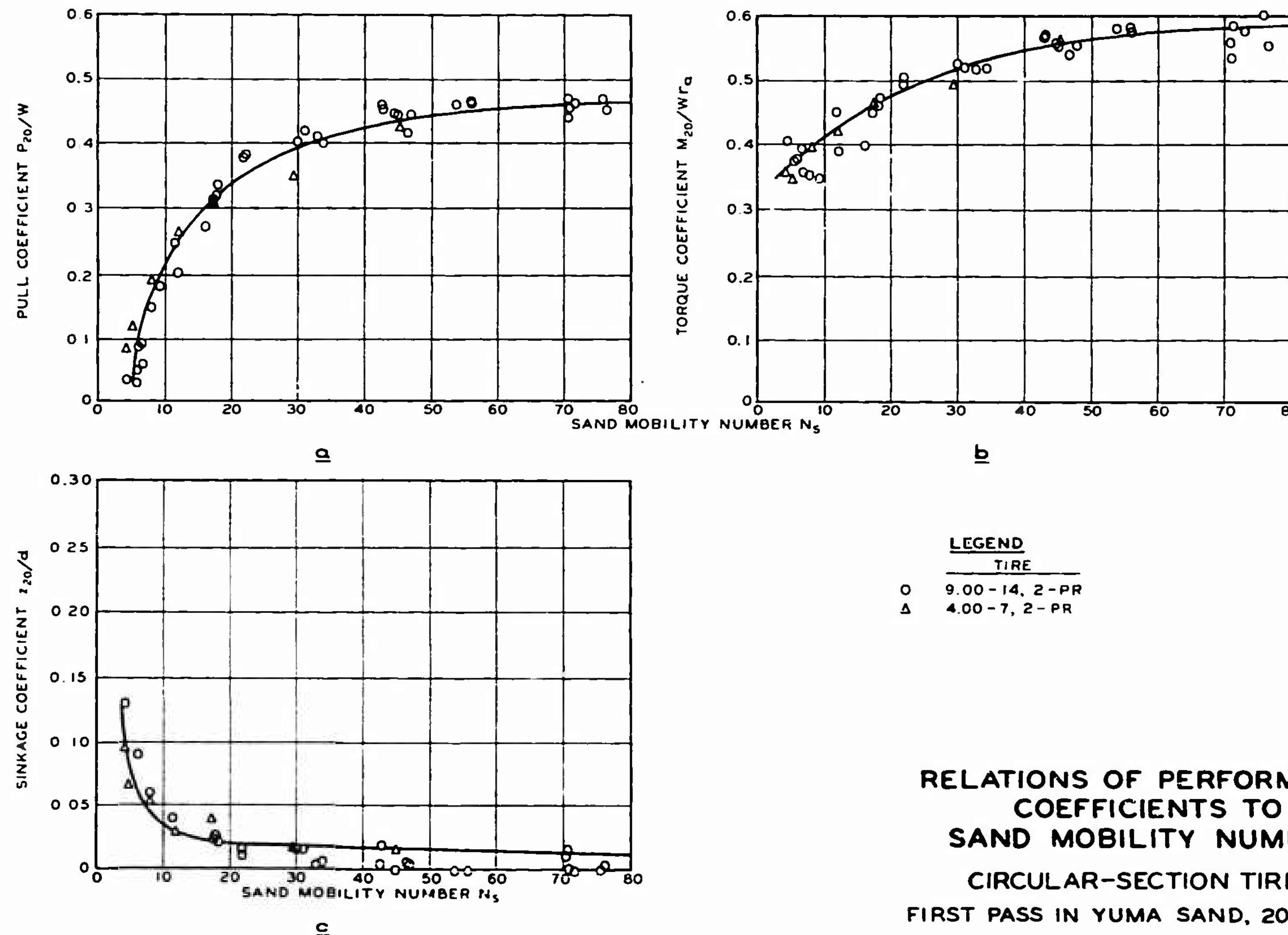
Table 3 (Continued)

Tire	Test No.	Pass No.	Test Condition	Penetration Resistance Gradient G 0-16 cm MN/m^3	Deflection δ/h	Load W, N Design	Load W, N Test	Pull P N	Pull Coefficient P/W	Torque M m-N	Coefficient M/Wr_a	Sinkage z, cm	Sinkage Coefficient z/d	Towed Force P_T, N	Towed Force Coefficient P_T/W	Sand Mobility Number N_s	N_{se}
							Yuma Sand (Continued)										
16x15.00-6, 2-PR (Continued)	A68-0091-1	1	20% slip	1.92	0.25	3960	3910	290	0.074	314	0.386	4.4	0.098	--	--	8.9	--
		2	20% slip	1.92	0.25	3960	3930	-50	-0.013	271	0.332	--	--	--	--	8.8	--
		3	20% slip	1.92	0.25	3960	3930	-70	-0.018	238	0.291	--	--	--	--	8.8	--
	A68-0090-1	1	20% slip	1.28	0.25	3960	3940	-280	-0.071	313	0.382	7.1	0.158	--	--	5.9	--
		2	20% slip	1.28	0.25	3960	3920	-250	-0.064	263	0.323	--	--	--	--	5.9	--
		3	20% slip	1.28	0.25	3960	3920	-160	-0.041	249	0.305	--	--	--	--	5.9	--
	A68-0089-1	1	20% slip	1.37	0.35	2020	2040	490	0.240	176	0.440	2.7	0.062	--	--	16.3	--
		1	Towed	1.37	0.35	2020	2080	--	--	--	--	--	--	240	0.115	16.0	--
		2	20% slip	1.37	0.35	2020	2030	400	0.197	154	0.387	--	--	--	--	16.4	--
		3	20% slip	1.37	0.35	2020	2020	430	0.213	148	0.374	--	--	--	--	16.5	--
	A68-0094-1	1	20% slip	3.03	0.35	2020	2040	920	0.451	224	0.560	0.2	0.005	--	--	36.1	--
		1	Towed	3.03	0.35	2020	2040	--	--	--	--	--	--	90	0.044	36.1	--
		2	20% slip	3.03	0.35	2020	2040	640	0.314	188	0.470	--	--	--	--	36.1	--
		3	20% slip	3.03	0.35	2020	2010	520	0.259	164	0.416	--	--	--	--	36.7	--
26x16.00-10, 4-PR	A68-101-1	1	20% slip	1.75	0.15	2020	2000	560	0.280	243	0.408	1.6	0.026	--	--	16.7	--
		1	Towed	1.75	0.15	2020	2040	--	--	--	--	--	--	160	0.078	16.4	--
		2	20% slip	1.75	0.15	2020	2040	340	0.167	202	0.333	--	--	--	--	16.4	--
		3	20% slip	1.75	0.15	2020	2020	320	0.158	194	0.323	--	--	--	--	16.6	--
	A68-0100-1	1	20% slip	1.36	0.15	3960	3790	300	0.079	411	0.362	5.5	0.088	--	--	6.9	--
		1	Towed	1.36	0.15	3960	3850	--	--	--	--	--	--	780	0.203	6.8	--
		2	20% slip	1.36	0.15	3960	3840	160	0.042	356	0.310	--	--	--	--	6.8	--
		3	20% slip	1.36	0.15	3960	3840	190	0.049	320	0.278	--	--	--	--	6.8	--
	A68-0102-1	1	20% slip	3.24	0.25	2020	2070	970	0.469	333	0.559	0.0	0.000	--	--	49.2	--
		1	Towed	3.24	0.25	2020	2080	--	--	--	--	--	--	60	0.029	49.0	--
		2	20% slip	3.24	0.25	2020	2070	800	0.387	283	0.475	--	--	--	--	49.2	--
		3	20% slip	3.24	0.25	2020	2060	720	0.350	265	0.447	--	--	--	--	49.5	--
	A68-0105-1	1	20% slip	1.61	0.25	5720	5640	1070	0.190	646	0.393	3.8	0.061	--	--	9.2	--
		1	Towed	1.61	0.25	5720	5710	--	--	--	--	--	--	720	0.126	9.1	--
		2	20% slip	1.61	0.25	5720	5660	720	0.127	560	0.339	--	--	--	--	9.2	--
		3	20% slip	1.61	0.25	5720	5640	600	0.106	523	0.318	--	--	--	--	9.2	--
	A68-0103-1	1	20% slip	3.28	0.35	3960	4000	1490	0.372	590	0.526	0.5	0.008	--	--	36.1	--
		1	Towed	3.28	0.35	3960	3980	--	--	--	--	--	--	430	0.108	36.3	--
		2	20% slip	3.28	0.35	3960	4000	1240	0.310	524	0.467	--	--	--	--	36.1	--
		3	20% slip	3.28	0.35	3960	3990	1170	0.293	497	0.444	--	--	--	--	36.2	--
	A68-0104-1	1	20% slip	1.09	0.35	4540	4550	880	0.193	560	0.439	5.3	0.086	--	--	10.6	--
		1	Towed	1.09	0.35	4540	4610	--	--	--	--	--	--	720	0.156	10.4	--
		2	20% slip	1.09	0.35	4540	4520	980	0.217	536	0.423	--	--	--	--	10.6	--
		3	20% slip	1.09	0.35	4540	4530	1040	0.230	523	0.412	--	--	--	--	10.6	--
31x15.50-13, 4-PR	A68-0111-1	1	20% slip	4.74	0.15	2020	2000	910	0.455	416	0.574	0.7	0.009	--	--	54.7	--
		1	Towed	4.74	0.15	2020	2000	--	--	--	--	--	--	20	0.010	54.7	--
		2	20% slip	4.74	0.15	2020	2040	860	0.422	395	0.534	--	--	--	--	53.7	--
		3	20% slip	4.74	0.15	2020	2040	590	0.289	319	0.431	--	--	--	--	53.7	--
	A68-0106-1	1	20% slip	1.77	0.15	4450	4350	800	0.184	679	0.428	4.8	0.063	--	--	9.5	--
		2	20% slip	1.77	0.15	4450	4340	580	0.134	584	0.369	--	--	--	--	9.6	--
		3	20% slip	1.77	0.15	4450	4370	570	0.130	534	0.335	--	--	--	--	9.5	--
	A68-0109-1	1	20% slip	0.88	0.25	3960	3840	680	0.177	550	0.406	5.5	0.073	--	--	8.8	--
		2	20% slip	0.88	0.25	3960	3900	800	0.205	552	0.401	--	--	--	--	8.7	--
		3	20% slip	0.88	0.25	3960	3900	840	0.215	538	0.391	--	--	--	--	8.7	--

(Continued)

Table 3 (Concluded)

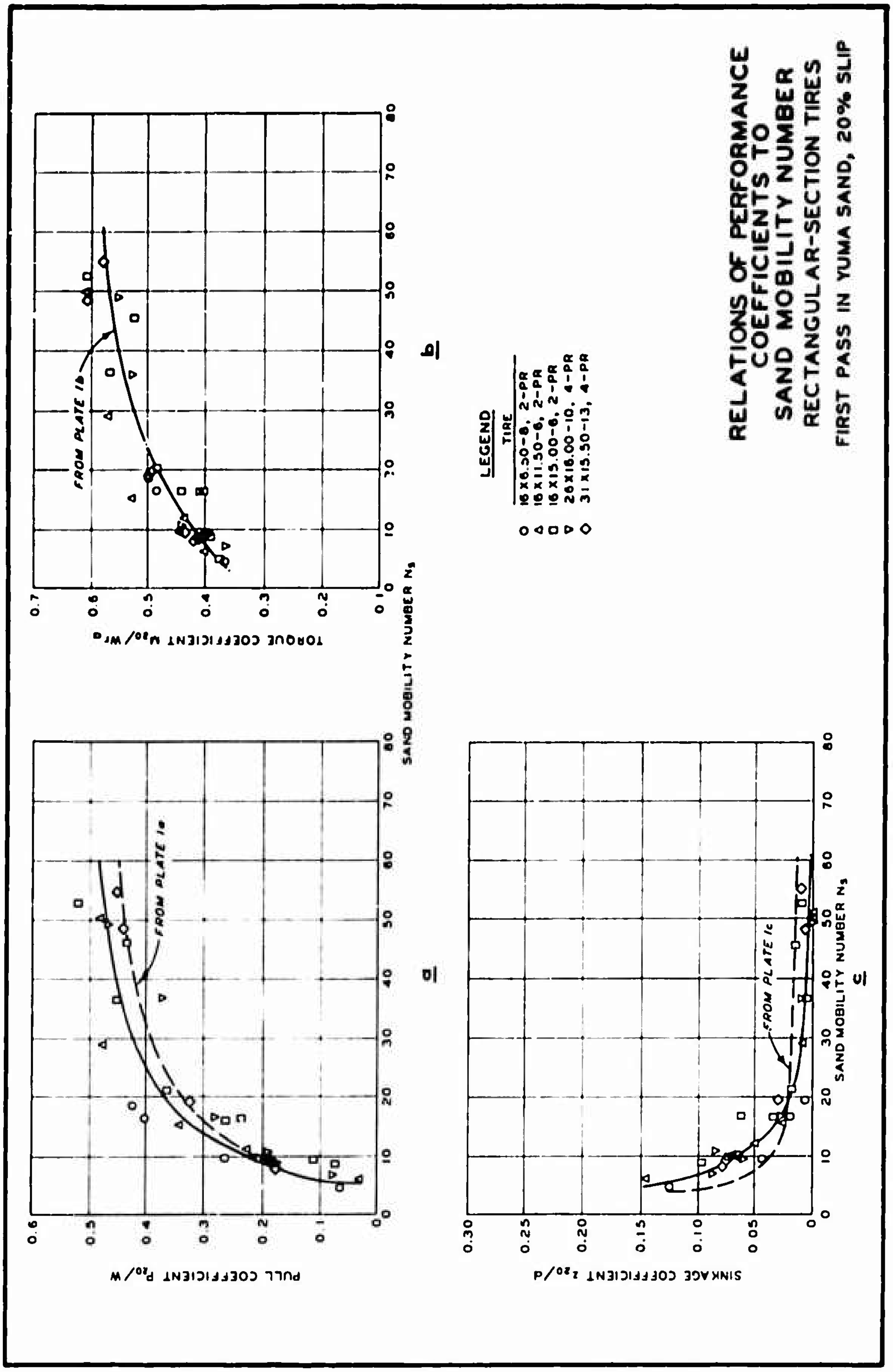
Tire	Test No.	Pass No.	Test Condition	Penetration Resistance Gradient G 0-16 cm MN/m^3	Deflection δ/h	Load W, N Design	Load W, N Test	Pull P N	Pull Coefficient P/W	Torque M m-N	Torque Coefficient M/Wr_a	Sinkage z, cm	Sinkage Coefficient z/d	Towed Force P_T, N	Towed Force Coefficient P_T/W	Sand Mobility Number N_s	Sand Mobility Number N_{se}
								Yuma Sand (Continued)									
31x15.50-13, 4-PR (Continued)	A68-0107-1	1	20% slip	2.66	0.25	5340	5360	1730	0.323	927	0.486	2.3	0.030	--	--	19.3	--
		1	Towed	2.66	0.25	5340	5360	--	--	--	--	--	--	310	0.058	19.3	--
		2	20% slip	2.66	0.25	5340	5320	1160	0.218	766	0.405	--	--	--	--	19.5	--
		3	20% slip	2.66	0.25	5340	5520	1080	0.196	731	0.373	--	--	--	--	13.8	--
	A68-0110-1	1	20% slip	3.55	0.35	3960	3960	1740	0.439	813	0.600	0.4	0.005	--	--	48.1	--
		1	Towed	3.55	0.35	3960	3950	--	--	--	--	--	--	170	0.043	48.2	--
		2	20% slip	3.55	0.35	3960	3920	1400	0.357	715	0.533	--	--	--	--	48.6	--
		3	20% slip	3.55	0.35	3960	3960	1280	0.323	688	0.508	--	--	--	--	48.1	--
	A68-0108-1	1	20% slip	0.87	0.35	6000	5920	1040	0.176	848	0.416	6.0	0.079	--	--	8.0	--
		2	20% slip	0.87	0.35	6000	5990	1320	0.220	855	0.414	--	--	--	--	7.9	--
		3	20% slip	0.87	0.35	6000	5970	1430	0.240	864	0.420	--	--	--	--	7.9	--
								Mortar Sand									
16x6.50-8, 2-PR	A69-0022-2	1	20% slip	3.47	0.15	1000	950	120	0.126	49	0.260	1.2	0.029	--	--	9.4	6.8
		1	Towed	3.47	0.15	1000	1010	--	--	--	--	--	--	100	0.099	8.9	6.4
	A69-0023-2	1	20% slip	4.05	0.25	1000	940	240	0.255	70	0.390	0.2	0.005	--	--	18.1	13.2
		1	Towed	4.05	0.25	1000	1000	--	--	--	--	--	--	70	0.070	17.0	12.4
	A69-0024-2	1	20% slip	6.08	0.35	2020	1980	520	0.263	145	0.390	0.0	0.000	--	--	18.4	13.6
		1	Towed	6.08	0.35	2020	2050	--	--	--	--	--	--	80	0.039	17.7	13.2
16x11.50-6, 2-PR	A69-0019-2	1	20% slip	2.09	0.15	1000	940	150	0.160	61	0.310	1.1	0.025	--	--	14.5	10.1
		1	Towed	2.09	0.15	1000	970	--	--	--	--	--	--	100	0.103	14.1	9.8
	A69-0033-2	1	20% slip	3.29	0.15	1000	930	260	0.280	81	0.416	0.6	0.014	--	--	23.1	16.6
		1	Towed	3.29	0.15	1000	960	--	--	--	--	--	--	60	0.063	22.4	16.1
	A69-0020-2	1	20% slip	2.04	0.25	2020	1950	340	0.174	147	0.371	1.9	0.043	--	--	11.4	7.9
		1	Towed	2.04	0.25	2020	2000	--	--	--	--	--	--	200	0.100	11.1	7.7
	A69-0021-2	1	20% slip	3.97	0.35	3960	3950	1020	0.258	339	0.431	1.2	0.027	--	--	15.6	11.3
		1	Towed	3.97	0.35	3960	3990	--	--	--	--	--	--	240	0.060	15.5	11.2
16x15.00-6, 2-PR	A69-0032-2	1	20% slip	2.44	0.15	1000	960	230	0.240	77	0.387	0.8	0.018	--	--	26.9	18.9
		1	Towed	2.44	0.15	1000	990	--	--	--	--	--	--	40	0.040	26.1	18.4
	A69-0031-2	1	20% slip	2.12	0.25	3960	3870	240	0.062	254	0.316	3.5	0.078	--	--	9.9	6.9
		1	Towed	2.12	0.25	3960	3940	--	--	--	--	--	--	930	0.236	9.7	6.8
	A69-0001-2	1	20% slip	0.89	0.35	2020	1990	350	0.176	164	0.425	3.5	0.081	--	--	10.9	7.2
		1	Towed	0.89	0.35	2020	2010	--	--	--	--	--	--	270	0.134	10.8	7.1
26x16.00-10, 4-PR	A69-0025-2	1	20% slip	1.42	0.15	3960	3920	260	0.066	410	0.350	5.5	0.089	--	--	7.0	4.8
		1	Towed	1.42	0.15	3960	4000	--	--	--	--	--	--	930	0.233	6.9	4.7
	A69-0026-2	1	20% slip	1.97	0.25	5720	5500	910	0.165	579	0.362	3.0	0.048	--	--	11.5	8.0
		1	Towed	1.97	0.25	5720	5620	--	--	--	--	--	--	610	0.109	11.3	7.8
	A69-0027-2	1	20% slip	3.20	0.35	3960	3980	1440	0.362	569	0.509	0.0	0.000	--	--	35.4	25.3
		1	Towed	3.20	0.35	3960	3990	--	--	--	--	--	--	230	0.058	35.3	25.3
31x15.50-13, 4-PR	A69-0028-2	1	20% slip	4.61	0.15	2020	2000	830	0.415	357	0.493	0.0	0.000	--	--	53.2	38.9
		1	Towed	4.61	0.15	2020	2020	--	--	--	--	--	--	40	0.020	52.7	38.5
	A69-0030-2	1	20% slip	2.62	0.25	5340	5210	1430	0.274	782	0.422	2.0	0.026	--	--	19.6	13.8
		1	Towed	2.62	0.25	5340	5400	--	--	--	--	--	--	260	0.048	18.9	13.3
	A69-0029-2	1	20% slip	0.86	0.35	6000	5820	1080	0.186	811	0.405	5.5	0.073	--	--	8.0	5.3
		1	Towed	0.86	0.35	6000	5970	--	--	--	--	--	--	690	0.116	7.8	5.2



RELATIONS OF PERFORMANCE COEFFICIENTS TO SAND MOBILITY NUMBER

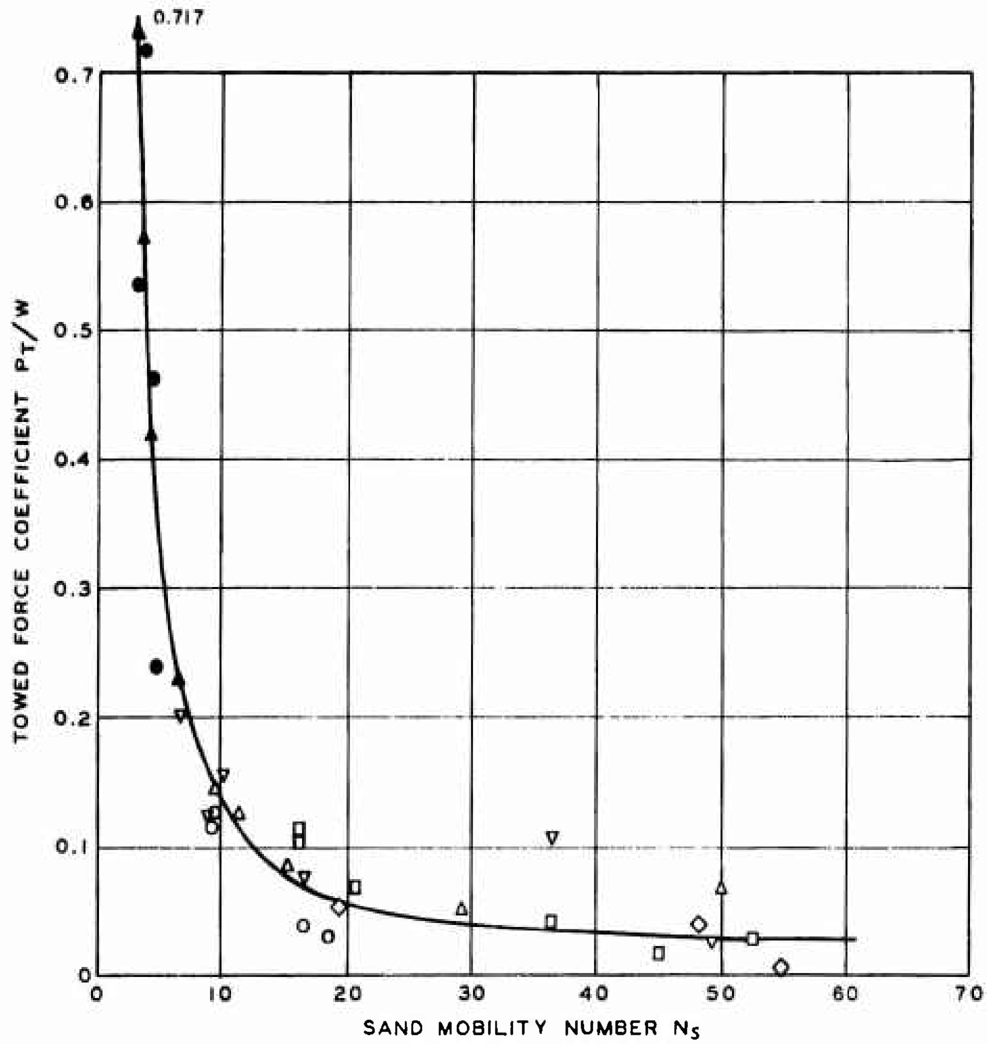
CIRCULAR-SECTION TIRES

FIRST PASS IN YUMA SAND, 20% SLIP



RELATIONS OF PERFORMANCE
COEFFICIENTS TO
SAND MOBILITY NUMBER
RECTANGULAR-SECTION TIRES
FIRST PASS IN YUMA SAND, 20% SLIP
LEGEND
TIRE
16 X 6.50-8, 2-PR
16 X 11.50-6, 2-PR
16 X 15.00-6, 2-PR
26 X 16.00-10, 4-PR
31 X 15.50-13, 4-PR
PULL COEFFICIENT P20/W
TORQUE COEFFICIENT M20/Wrd
SINKAGE COEFFICIENT z20/d
SAND MOBILITY NUMBER Ns
FROM PLATE 1a
FROM PLATE 1b
FROM PLATE 1c
a
b
c

PLATE 2

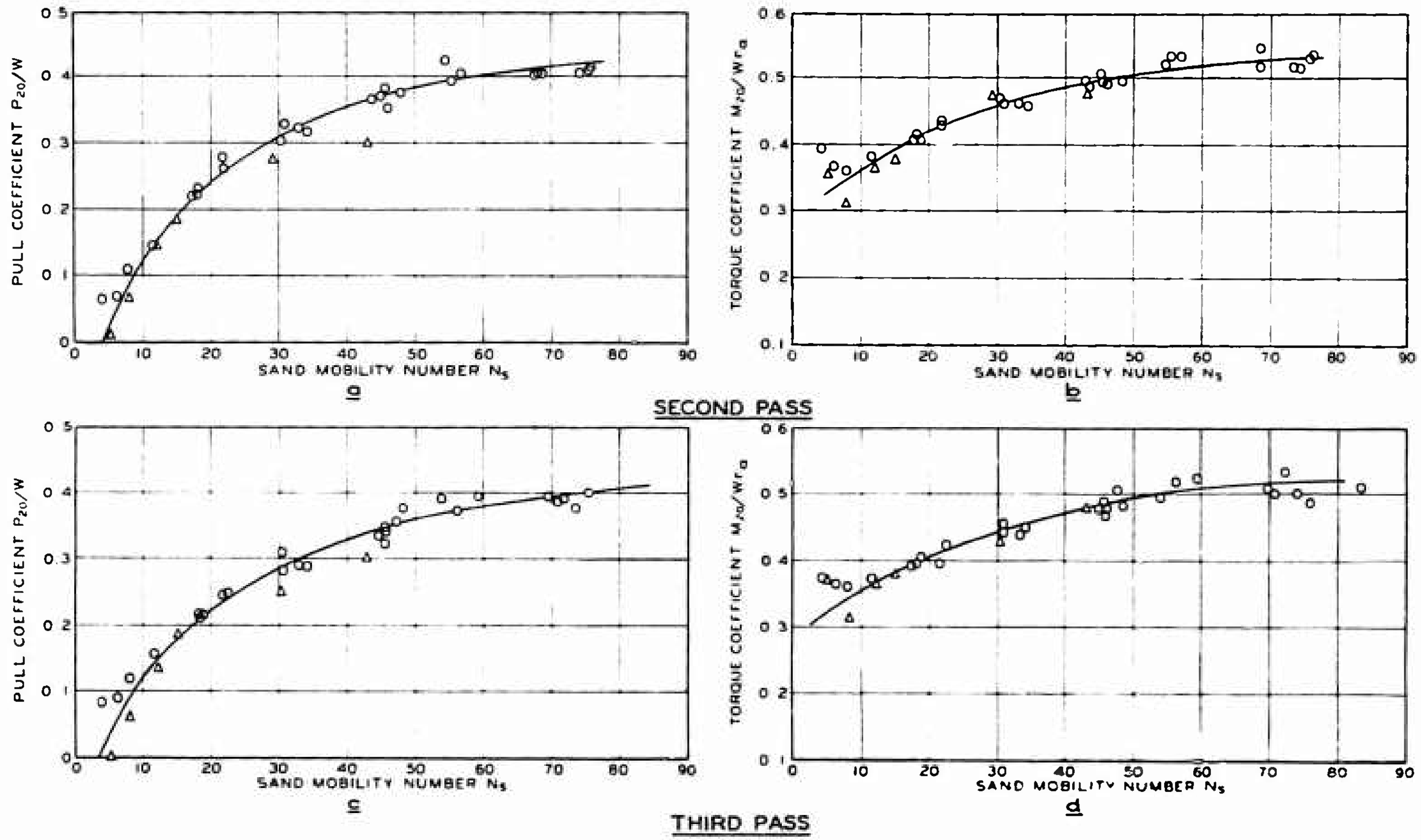


LEGEND

	TIRE
O	16X6.50-8, 2-PR
Δ	16X11.50-6, 2-PR
□	16X15.00-6, 2-PR
∇	26X16.00-10, 4-PR
◇	31X15.50-13, 4-PR

NOTE: CLOSED SYMBOLS REPRESENT TOWED TESTS.

RELATION OF
TOWED FORCE COEFFICIENT
TO SAND MOBILITY NUMBER
RECTANGULAR-SECTION TIRES
FIRST PASS IN YUMA SAND, 20% SLIP



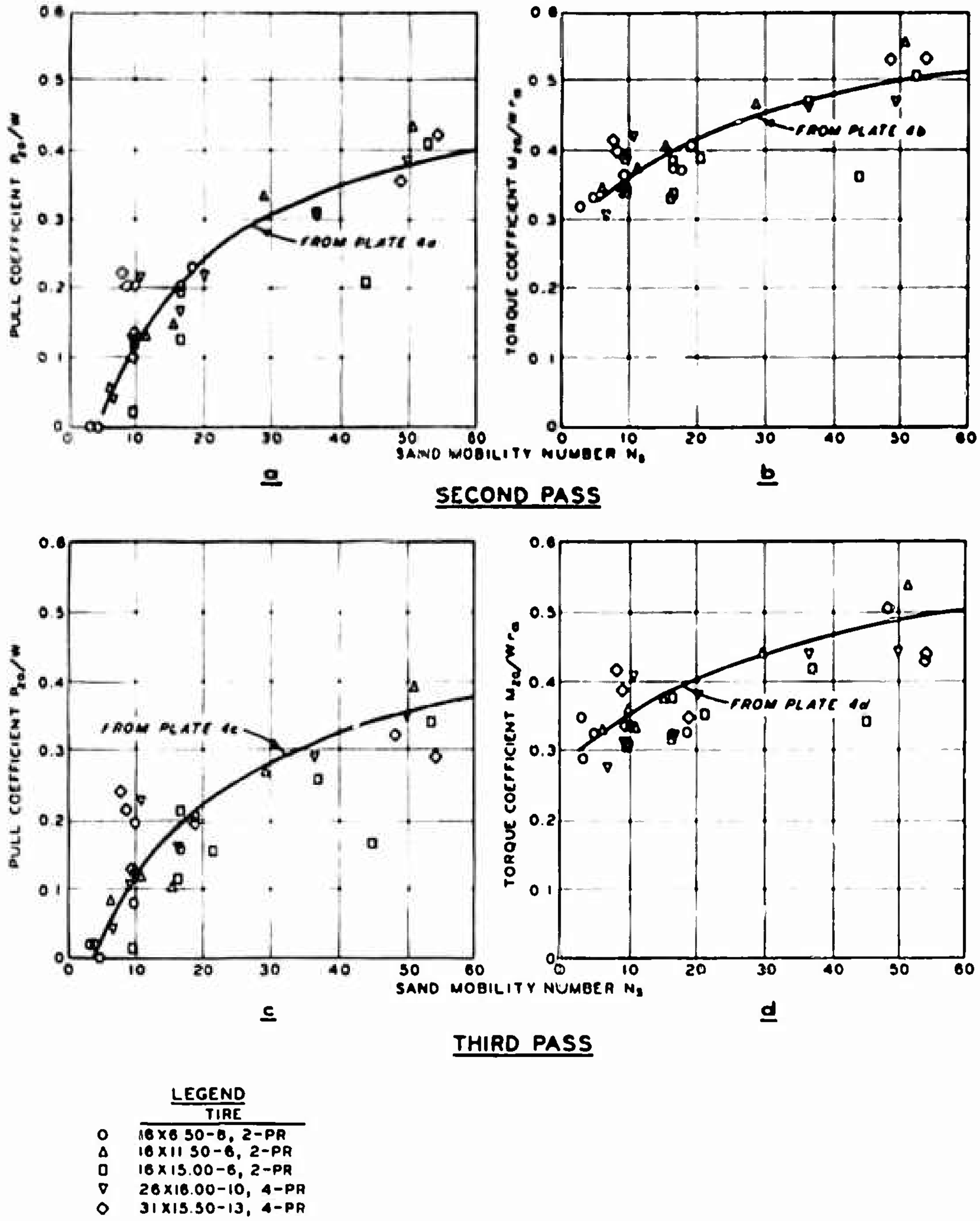
LEGEND

	TIRE
O	9.00-14, 2-PR
Δ	4.00-7, 2-PR

RELATIONS OF PULL AND TORQUE COEFFICIENTS TO SAND MOBILITY NUMBER

CIRCULAR-SECTION TIRES

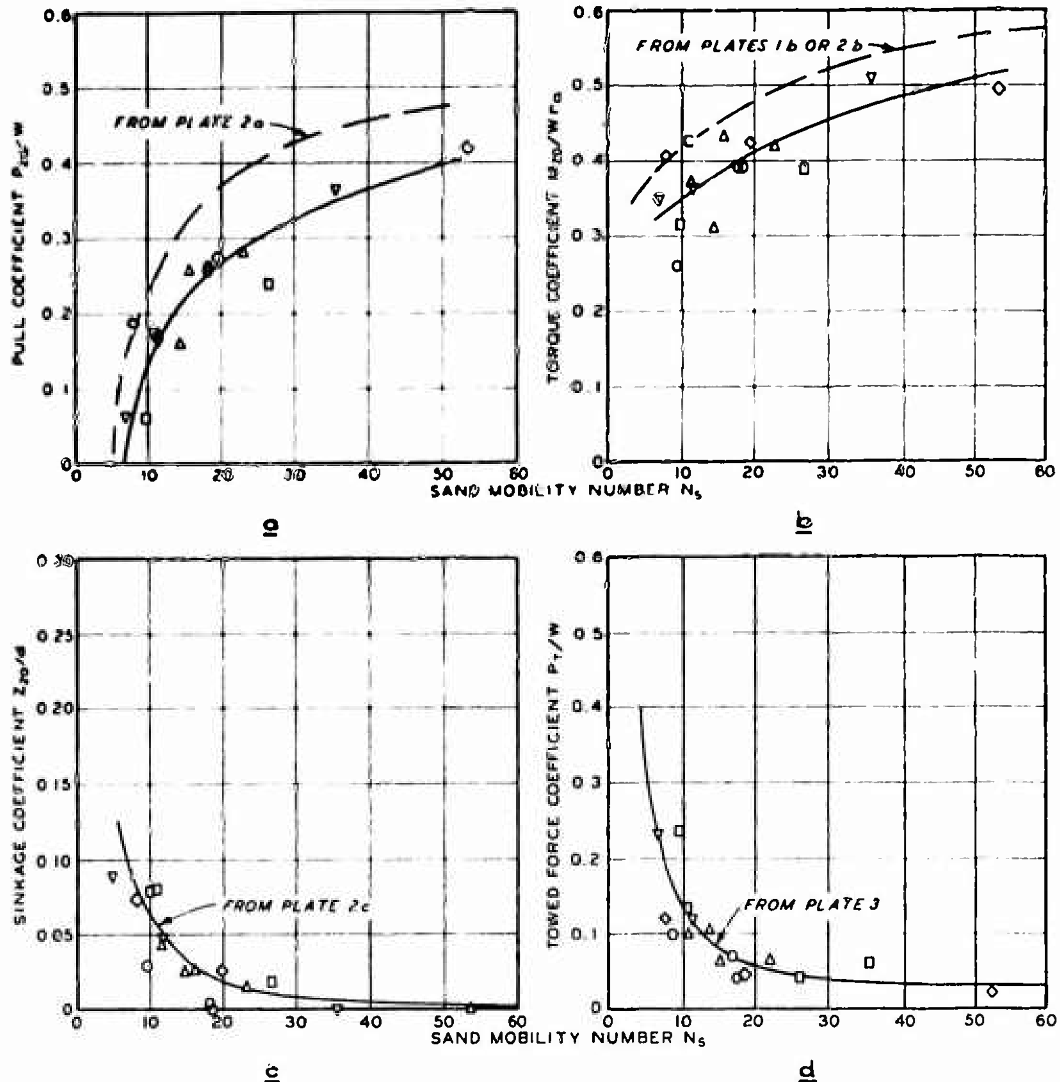
SECOND AND THIRD PASSES IN YUMA SAND, 20% SLIP



RELATIONS OF PULL AND TORQUE COEFFICIENTS TO SAND MOBILITY NUMBER

RECTANGULAR-SECTION TIRES

SECOND AND THIRD PASSES IN YUMA SAND, 20% SLIP



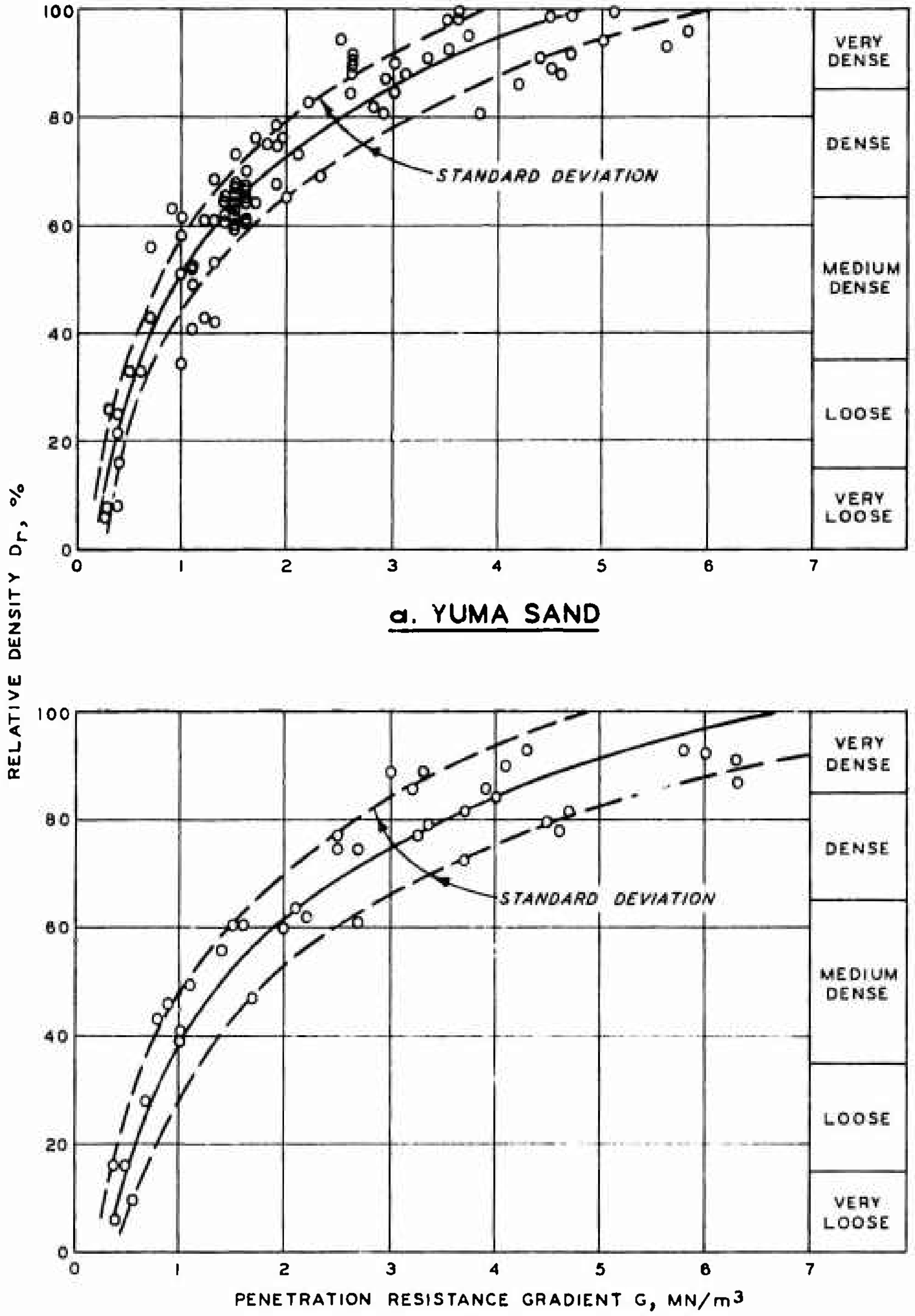
LEGEND

TIRE
O 16 X 6.50-8, 2-PR
Δ 16 X 11.50-6, 2-PR
□ 16 X 15.50-6, 2-PR
▽ 26 X 16.00-10, 4-PR
◇ 31 X 15.50-13, 4-PR

RELATIONS OF PERFORMANCE COEFFICIENTS TO SAND MOBILITY NUMBER

RECTANGULAR-SECTION TIRES

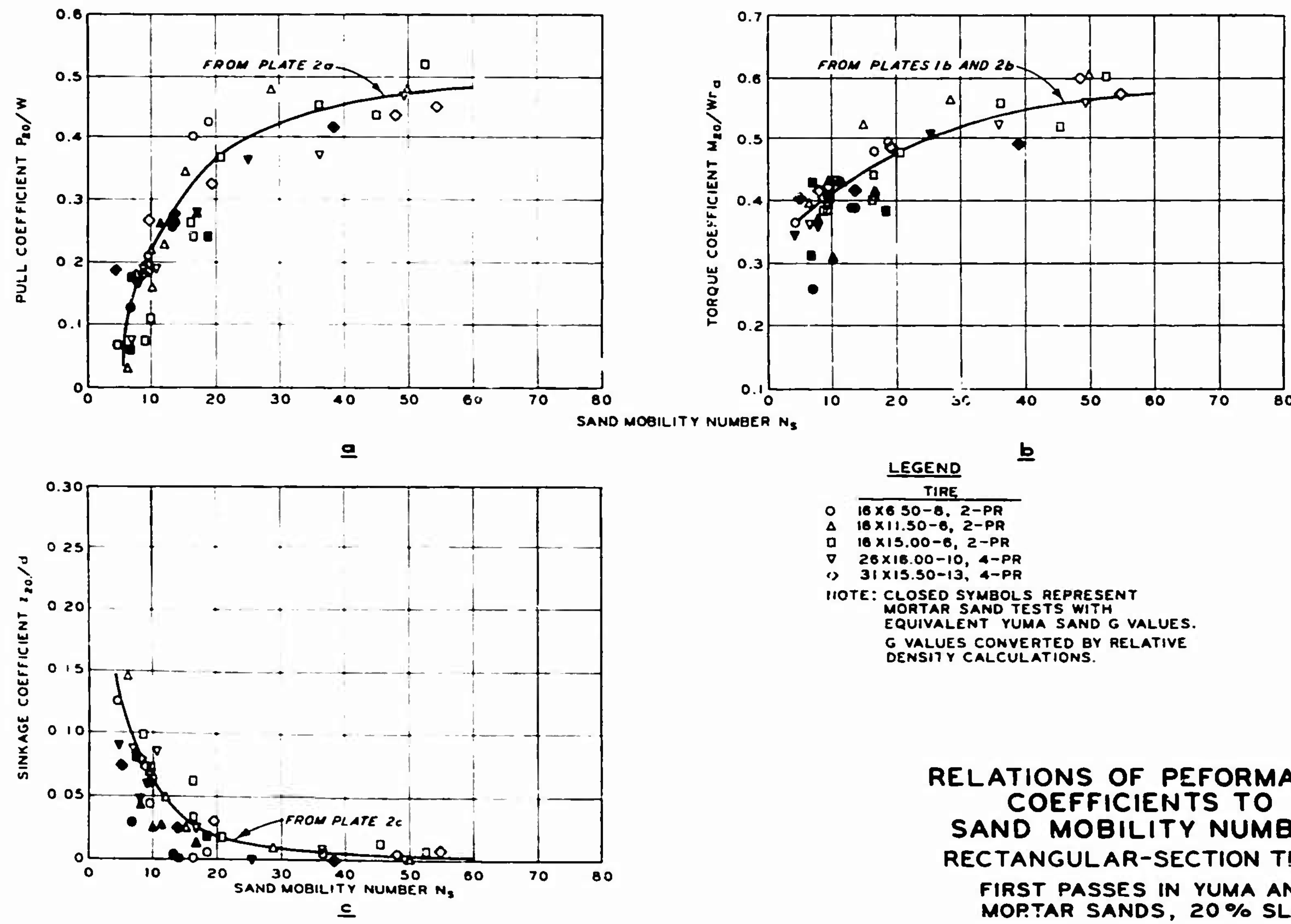
FIRST PASS IN MORTAR SAND, 20% SLIP



a. YUMA SAND

b. MORTAR SAND

RELATIONS OF RELATIVE DENSITY TO PENETRATION RESISTANCE GRADIENT
YUMA AND MORTAR SANDS
(ADAPTED FROM REFERENCE 6)



RELATIONS OF PEFORMANCE COEFFICIENTS TO SAND MOBILITY NUMBER

RECTANGULAR-SECTION TIRES

FIRST PASSES IN YUMA AND MORTAR SANDS, 20% SLIP